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DESCRIPTION

PULSE TUBE REFRIGERATOR

TECHNICAL FIELD

【0001】 The present invention relates to a pulse tube refrigerator for generating ultracold temperatures.

BACKGROUND ART

【0002】 As a prior art, a pulse tube refrigerator illustrated in Fig. 8 (Patent Literature No. 1: Japanese Unexamined Patent Publication (KOKAI) No. 9-296,963) has been known. This pulse tube refrigerator has a compressor 121, low-pressure supply valves 122, 124, 126, high-pressure supply valves 123, 125, 127, a first pulse tube 107, a second pulse tube 117, a first cold accumulator 103, and a second cold accumulator 13, as shown in Fig. 8. The first pulse tube 107 has a high-temperature end 107H, and a low-temperature end 107L. The second pulse tube 117, which is on a much lower temperature side, has a high-temperature end 117H, and a low-temperature end 117L.

【0003】 In accordance with this pulse tube refrigerator, the high-temperature end 117H of the second pulse tube 117 is disposed in a room-temperature portion, and is cooled by air. Accordingly, since the volume of the second pulse tube 117 becomes large, there is a limitation on enhancing the compression ratio of refrigerant gas within a cooling circuit, consequently, there has been a limitation on enhancing the cooling capacity generating at a lower end, which is one of the opposite-end sides of the second pulse tube 117.

【0004】 Moreover, in accordance with this pulse tube refrigerator, a warm gas, which is a room temperature or more, flows into the

low-temperature end of the second pulse tube 117 from the high-temperature end 117H of the second pulse tube 117, there has been a limitation on enhancing the cooling capacity generating at the low-temperature end 117L of the second pulse tube 117, in this sense as well.

【0005】 Moreover, as a prior art, there is a pulse tube refrigerator disclosed in a literature (Non-patent literature No. 1: Cryocoolers, 11, P189-198 Design and Test of the NIST/Lockeed Martin Minituature Pulse Tube Fligt Cryosooler) illustrated in Fig. 9. This pulse tube refrigerator has a compressor 209, a first pulse tube 201, a second pulse tube 203, a first cold accumulator 207, a second cold accumulator 206, and orifices 300, 301, 302, as shown in Fig. 9. The first pulse tube 201 has a high-temperature end 201H, and a low-temperature end 201L. The second pulse tube 203, which is on a much lower temperature side, has a high-temperature end 203H, and a low-temperature end 203L.

【0006】 In accordance with this pulse tube refrigerator, the high-temperature end 203H of the second pulse tube 203 is disposed to be connected with the low-temperature end 201L of the first pulse tube 201. Accordingly, the high-temperature end 203H of the second pulse tube 203 is cooled by refrigeration generating at the first pulse tube 201, but, since the high-temperature end 203H of the second pulse tube 203 is simply disposed on the low-temperature end 201L of the first pulse tube 201, no favorable cooling capacity can be obtained at the low-temperature end 203L of the second pulse tube 203, even if the gas compression ratio of refrigerant gas is large.

(Patent Literature No. 1: Japanese Unexamined Patent Publication (KOKAI) No. 9-296,963)

(Non-patent literature No. 1: Cryocoolers, 11, P189-198 Design and Test of the NIST/Lockeed Martin Minituature Pulse Tube Fligt Cryosooler)

DISCLOSURE OF THE INVENTION

【0007】 The present invention is done in view of the aforementioned circumstances, and provides a pulse tube refrigerator which is advantageous for enhancing the cooling capacity.

【0008】 (1) A first aspect of a pulse tube refrigerator of the present invention comprises: a pressure-waveform generating device for generating a pressure waveform of refrigerant gas;

a pulse tube into which refrigerant gas with the pressure waveform generated by the pressure-waveform generating device flows, one of whose ends is adapted to a low-temperature end, and the other one of whose ends is adapted to a high-temperature end;

a cold accumulator disposed between the pressure-waveform generating device and the pulse tube, and pre-cooling the refrigerant gas to be flowed into the pulse tube;

a pressure-waveform phase controlling element having a buffer tank communicating with the high-temperature end of the pulse tube, and controlling a pressure-waveform phase of the refrigerant gas for generating refrigeration at the low-temperature end of the pulse tube; and

a vacuum heat-insulation bath having a vacuum heat-insulation chamber for accommodating the pulse tube,

wherein the pulse tube refrigerator is characterized in that the buffer tank is placed within the vacuum heat-insulation chamber of the vacuum heat-insulation bath.

【0009】 In accordance with the first aspect of the pulse tube

refrigerator of the present invention, the buffer tank is placed within the vacuum heat-insulation chamber of the vacuum heat-insulation bath, along with the pulse tube. Accordingly, the heat of air is inhibited from entering the buffer tank. Therefore, it is possible to maintain the refrigerant gas within the buffer tank at a low temperature. Consequently, it is possible to enhance the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end of the pulse tube becomes large, and it becomes advantageous for enhancing the cooling capacity of the pulse tube refrigerator.

【0010】 In accordance with the first aspect of the pulse tube refrigerator of the present invention, when a first buffer tank and a second buffer tank are disposed, it is possible to place the second buffer tank, which is on a low-temperature side, within the vacuum heat-insulation bath.

【0011】 Note that, in accordance with the respective aspects of the present invention, the pressure-waveform generating device generates a pressure waveform of refrigerant gas, and can be formed using compressors, for example. The cold accumulator is disposed between the pressure-waveform generating device and the pulse tube, and has a function of cooling the refrigerant gas to be flowed into the pulse tube. The cold accumulator can be formed using materials, such as metals, whose heat capacities are large.

【0012】 In accordance with the respective aspects of the present invention in the preset description, the inside of the vacuum heat-insulation chamber of the vacuum heat-insulation bath is maintained in a high-vacuum state, and can intend to obtain vacuum heat insulation. In this instance, as for the high-vacuum state,

it is possible to exemplify 10^{-3} Torr or less ($\fallingdotseq$ 133×10^{-3} Pa or less), more preferably, it is possible to exemplify 10^{-4} Torr or less ($\fallingdotseq$ 133×10^{-4} Pa or less).

【0013】 (2) A second aspect of a pulse tube refrigerator of the present invention comprises: a pressure-waveform generating device for generating a pressure waveform of refrigerant gas;

a pulse tube into which refrigerant gas with the pressure waveform generated by the pressure-waveform generating device flows, one of whose ends is adapted to a low-temperature end, and the other one of whose ends is adapted to a high-temperature end;

a cold accumulator disposed between the pressure waveform generating device and the pulse tube, and pre-cooling the refrigerant gas to be flowed into the pulse tube;

a pressure-waveform phase controlling element having an inertance tube communicating with the high-temperature end of the pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the pulse tube, a buffer tank communicating with the high-temperature end of the pulse tube by way of the inertance tube, and controlling a pressure-waveform phase of the refrigerant gas for generating refrigeration at the low-temperature end of the pulse tube; and

a vacuum heat-insulation bath having a vacuum heat-insulation chamber for accommodating the pulse tube,

wherein the pulse tube refrigerator is characterized in that the inertance tube is placed within the vacuum heat-insulation chamber of the vacuum heat-insulation bath.

【0014】 In accordance with the second aspect of the pulse tube refrigerator of the present invention, the refrigerant gas at the

high-temperature end of the pulse tube flows in and flows out with respect to the buffer tank by way of the inertance tube, which has a flow passage with a smaller inside diameter than an inside diameter of the pulse tube. At this moment, a pressure-waveform phase of the refrigerant gas is adjusted so that refrigeration at the low-temperature end of the pulse tube is generated favorably. The inertance tube functions as the pressure-waveform phase controlling element for adjusting the phase and pressure amplitude of the refrigerant gas, together with the buffer tank. In the viewpoint of having the function of adjusting the pressure-waveform phase of the refrigerant gas, the inertance tube plays a function of inductance in electric circuit (a function of generating a phase difference of the refrigerant gas), when considering its correspondence to electric circuit.

【0015】 In accordance with the second aspect of the pulse tube refrigerator of the present invention, the inertance tube is placed within the vacuum heat-insulation chamber of the vacuum heat-insulation bath, along with the pulse tube. Accordingly, the heat of air is inhibited from entering the inertance tube. Therefore, it is possible to maintain the refrigerant gas flowing in the inertance tube at a low temperature. Consequently, it is possible to enhance the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end of the pulse tube becomes large, and it becomes advantageous for enhancing the cooling capacity of the pulse tube refrigerator.

【0016】 Especially, when the refrigerant gas, which flows in the inertance tube, is a low temperature, a flow-passage resistance of

the inertance tube becomes smaller, and it is possible to make a viscosity loss of the gas, which flows within the inertance tube, small. As a result, since it is possible to make a phase and gas amount of the refrigerant gas, which flows into the high-temperature end of the pulse tube, favorable, the cooling capacity enlarges.

【0017】 In accordance with the second aspect of the pulse tube refrigerator of the present invention, when a first inertance tube communicating with a first buffer tank, and a second inertance tube communicating with a second buffer tank are disposed, it is possible to place the second inertance tube, which is on a low-temperature side, within the vacuum heat-insulation bath.

【0018】 (3) A third aspect of a pulse tube refrigerator of the present invention comprises: a pressure-waveform generating device for generating a pressure waveform of refrigerant gas;

a first pulse tube into which refrigerant gas with the pressure waveform generated by the pressure-waveform generating device flows, one of whose ends is adapted to a low-temperature end, and the other one of whose ends is adapted to a high-temperature end;

a second pulse tube into which refrigerant gas with a pressure waveform flows, one of whose ends is adapted to a low-temperature end, the low-temperature end becoming a lower temperature than the low-temperature end of the first pulse tube, and the other one of whose ends is adapted to a high-temperature end;

a cold accumulator disposed between the pressure-waveform generating device, the first pulse tube and the second pulse tube, and pre-cooling the refrigerant gas to be flowed into the first pulse tube and/or the second pulse tube;

a pressure-waveform phase controlling element having a first

inertance tube communicating with the high-temperature end of the first pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the first pulse tube, a first buffer tank communicating with the high-temperature end of the first pulse tube by way of the first inertance tube, a second inertance tube communicating with the high-temperature end of the second pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the second pulse tube, and a second buffer tank communicating with the high-temperature end of the second pulse tube by way of the second inertance tube, and controlling pressure-waveform phases of the refrigerant gas for generating refrigeration; and

a vacuum heat-insulation bath having a vacuum heat-insulation chamber for accommodating the second pulse tube at least,

wherein a cooling element contacting thermally with the low-temperature end of the first pulse tube and being cooled by refrigeration from the low-temperature end of the first pulse tube is disposed, and the cooling element is brought into contact with the second inertance tube thermally.

【0019】 In accordance with the third aspect of the pulse tube refrigerator of the present invention, the refrigerant gas at the high-temperature ends of the pulse tubes flows in and flows out with respect to the buffer tanks by way of the inertance tubes, which have flow passages with smaller inside diameters than inside diameters of the pulse tubes. At this moment, pressure-waveform phases of the refrigerant gas are adjusted so that refrigeration at the low-temperature ends of the pulse tubes is generated favorably. The inertance tubes function as the pressure-waveform phase

controlling element for adjusting the phases and pressure amplitudes of the refrigerant gas, together with the buffer tanks. In the viewpoint of having the function of adjusting the pressure-waveform phases of the refrigerant gas, the inertance tubes play a function of inductance in electric circuit, when considering their correspondence to electric circuit.

【0020】 Further, the cooling element, which contacts with the low-temperature end of the first pulse tube and is cooled by refrigeration from the low-temperature end of the first pulse tube, is disposed. Accordingly, the cooling element is cooled by refrigeration at the low-temperature end of the first pulse tube.

【0021】 Further, in accordance with the third aspect of the pulse tube refrigerator of the present invention, since the cooling element is brought into contact with the second inertance tube thermally, the second inertance tube is cooled by refrigeration from the low-temperature end of the first pulse tube. Accordingly, it is possible to maintain the refrigerant gas, which flows in the inertance tube, at a low temperature. Therefore, it is possible to enhance the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end of the pulse tube becomes large, and it becomes advantageous for enhancing the cooling capacity of the pulse tube refrigerator.

【0022】 Especially, when the refrigerant gas, which flows in the inertance tubes are low temperatures, flow-passage resistances of the inertance tubes become smaller, and it is possible to make viscosity losses of the gas, which flows within the inertance tubes, small, as a result, since it is possible to make phases and gas

amounts of the refrigerant gas, which flows into the high-temperature ends of the pulse tubes, favorable, the cooling capacity enlarges.

【0023】 As for the cooling element, it can preferably be formed of metals of favorable heat transferability. As for the cooling element, it is possible to exemplify plates. The shapes of plates are not limited in particular. In order to enhance the cooling ability with respect to the inertance tube, it is possible to enlarge a thermally contacting area between the cooling element and the inertance tube.

【0024】 (4) A fourth aspect of a pulse tube refrigerator of the present invention comprises: a pressure-waveform generating device for generating a pressure waveform of refrigerant gas;

a first pulse tube into which refrigerant gas with the pressure waveform generated by the pressure-waveform generating device flows, one of whose ends is adapted to a low-temperature end, and the other one of whose ends is adapted to a high-temperature end;

a second pulse tube into which refrigerant gas with a pressure waveform flows, one of whose ends is adapted to a low-temperature end, the low-temperature end becoming a lower temperature than the low-temperature end of the first pulse tube, and the other one of whose ends is adapted to a high-temperature end;

a cold accumulator disposed between the pressure-waveform generating device, the first pulse tube and the second pulse tube, and pre-cooling the refrigerant gas to be flowed into the first pulse tube and/or the second pulse tube;

a pressure-waveform phase controlling element having a first inertance tube communicating with the high-temperature end of the

first pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the first pulse tube, a first buffer tank communicating with the high-temperature end of the first pulse tube by way of the first inertance tube, a second inertance tube communicating with the high-temperature end of the second pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the second pulse tube, and a second buffer tank communicating with the high-temperature end of the second pulse tube by way of the second inertance tube, and controlling pressure-waveform phases of the refrigerant gas for generating refrigeration; and

a vacuum heat-insulation bath having a vacuum heat-insulation chamber for accommodating the second pulse tube at least,

wherein a cooling element contacting thermally with the low-temperature end of the first pulse tube and being cooled by refrigeration from the low-temperature end of the first pulse tube is disposed, and the cooling element is brought into contact with the second buffer tank thermally.

【0025】 In accordance with the fourth aspect of the pulse tube refrigerator of the present invention, the cooling element, which contacts with the low-temperature end of the first pulse tube and is cooled by refrigeration from the low-temperature end of the first pulse tube, is disposed. Accordingly, the cooling element is cooled by refrigeration at the low-temperature end of the first pulse tube.

【0026】 Further, in accordance with the fourth aspect of the pulse tube refrigerator of the present invention, since the cooling element is brought into contact with the second buffer tank thermally, the second buffer tank is cooled by refrigeration from the low-

temperature end of the first pulse tube. Accordingly, it is possible to maintain the refrigerant gas within the second buffer tank at a low temperature. Therefore, it is possible to enhance the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end of the pulse tube becomes large, and it becomes advantageous for enhancing the cooling capacity of the pulse tube refrigerator.

【0027】 The cooling element contacts thermally with the low-temperature end of the first pulse tube and is cooled by refrigeration from the low-temperature end of the first pulse tube. As for the cooling element, it can preferably be formed of metals of good heat transferability (aluminum alloys, copper alloys, iron alloys, and the like, in general). As for shapes of the cooling element, they are not limited in particular, but it is possible to exemplify plate shapes. The shapes of plates are not limited in particular. In order to enhance the cooling ability with respect to the second buffer tank, as for a thermally contacting area between the cooling element and the second buffer tank, it can be enlarged.

【0028】 (5) A fourth aspect of a pulse tube refrigerator of the present invention comprises: a pressure-waveform generating device for generating a pressure waveform of refrigerant gas;

a first pulse tube into which refrigerant gas with the pressure waveform generated by the pressure-waveform generating device flows, one of whose ends is adapted to a low-temperature end, and the other one of whose ends is adapted to a high-temperature end;

a second pulse tube into which refrigerant gas with a pressure waveform flows, one of whose ends is adapted to a low-temperature end, the low-temperature end becoming a lower temperature than the

low-temperature end of the first pulse tube, and the other one of whose ends is adapted to a high-temperature end;

a cold accumulator disposed between the pressure-waveform generating device, the first pulse tube and the second pulse tube, and pre-cooling the refrigerant gas to be flowed into the first pulse tube and the second pulse tube;

a pressure-waveform phase controlling element having a first inertance tube communicating with the high-temperature end of the first pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the first pulse tube, a first buffer tank communicating with the high-temperature end of the first pulse tube by way of the first inertance tube, a second inertance tube communicating with the high-temperature end of the second pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the second pulse tube, and a second buffer tank communicating with the high-temperature end of the second pulse tube by way of the second inertance tube, and controlling pressure-waveform phases of the refrigerant gas for generating refrigeration; and

a vacuum heat-insulation bath having a vacuum heat-insulation chamber for accommodating the second pulse tube at least,

wherein at least a part of the second inertance tube is brought into contact with the low-temperature end of the first pulse tube thermally.

【0029】 In accordance with the fifth aspect of the pulse tube refrigerator of the present invention, the second inertance tube is brought into contact with the low-temperature end of the first pulse tube thermally. In this instance, at least a part of the second

inertance tube is cooled by refrigeration from the low-temperature end of the first pulse tube. Accordingly, it is possible to maintain the refrigerant gas, which flows in the second inertance tube, at a low temperature. Consequently, it is possible to enhance the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end of the second pulse tube becomes large, and it becomes advantageous for enhancing the cooling capacity of the pulse tube refrigerator.

【0030】 Especially, since the inside diameter of the second inertance tube's flow passage is small so that, compared with the case where the inside diameter of the second inertance tube's flow passage is large, it is possible to efficiently cool the refrigerant gas, which flows on the central side of the second inertance tube, as well, in addition to the refrigerant gas, which flows on the outer-wall side of the second inertance tube, it is possible to efficiently cool the entirety of the refrigerant gas, which flows within the second inertance tube.

【0031】 In accordance with the fifth aspect of the pulse tube refrigerator of the present invention, it is possible to exemplify a mode in which the second inertance tube is brought into contact with the low-temperature end of the first pulse tube thermally by winding it around the lower-temperature end of the first pulse tube in a spiral shape.

(Effect of the Invention)

【0032】 In accordance with the present invention, it is possible to provide a pulse tube refrigerator which is advantageous for enhancing the refrigeration capacity generated at the low-temperature end of a pulse tube.

BRIEF DESCRIPTION OF THE DRAWINGS

【0033】 Fig. 1 relates to a First Embodiment Mode, and is a constructional diagram for illustrating the concept of a pulse tube refrigerator.

【0034】 Fig. 2 relates to the First Embodiment Mode, and is a constructional diagram for illustrating a contact portion between a second inertance tube and a shield plate.

【0035】 Fig. 3 relates to a Second Embodiment Mode, and is a constructional diagram for illustrating the concept of a pulse tube refrigerator.

【0036】 Fig. 4 relates to a Third Embodiment Mode, and is a constructional diagram for illustrating a contact state between a second inertance tube and a shield plate.

【0037】 Fig. 5 relates to a Fourth Embodiment Mode, and is a constructional diagram for illustrating the vicinity of a second buffer tank.

【0038】 Fig. 6 relates to a Fifth Embodiment Mode, and is a constructional diagram for illustrating the vicinity of a second buffer tank.

【0039】 Fig. 7 relates to a Sixth Embodiment Mode, and is a constructional diagram for illustrating a state in which a second inertance tube is wound around the low-temperature end of a first buffer tank.

【0040】 Fig. 8 relates to a prior art, and is a constructional diagram for illustrating the concept of a pulse tube refrigerator.

【0041】 Fig. 9 relates to a prior art, and is a constructional diagram for illustrating the concept of a pulse tube refrigerator.

BEST MODE FOR CARRYING OUT THE INVENTION

【0042】 Hereinafter, regarding the embodiment modes of the present invention, they will be described using the drawings.

(First Embodiment Mode)

【0043】 A First Embodiment Mode is illustrated in Fig. 1. In Fig. 1, 1 is a linearly-driving type compressor, and can function as a pressure-waveform generating device for generating a pressure waveform of gaseous refrigerant gas. In accordance with the compressor 1, the space between a piston 2 and a piston 3, which can move reciprocally, is adapted to a compression portion 4. The compression portion 4 communicates with an end 6a of a radiator 6 by way of a pipe 5, and another end 6b of the radiator 6 is connected with a first cold accumulator 8 in which a cold-accumulating material 7, such a wire net, is filled. At a low-temperature end 8b of the first cold accumulator 8, a cylinder-shaped connecting member 9, with which a second cold accumulator 10 is connected, is disposed. The inside of the second cold accumulator 10 is filled with a sphere-shaped cold-accumulating material 12, such as lead or rare-earth, which has a cold-accumulating function. The second cold accumulator 10 is maintained at a lower temperature than the first cold accumulator 8. Inside the connecting member 9, a flow-passage member 11 is disposed. The flow-passage member 11 is communicated with a first pulse tube 14 and a second pulse tube 20, and refrigerant gas, which is headed to the first pulse tube 14, and refrigerant gas, which is headed to the second pulse tube 20, flow.

【0044】 As shown in Fig. 1, on an outer wall surface, a circumferential surface of the aforementioned connecting member 9,

an end 13a of a pipe 13 for passing refrigerant is disposed. Another end 13b of the pipe 13 communicates with a first heat exchanger 15. The first heat exchanger 15 is disposed at a low-temperature end 14L of the first pulse tube 14.

【0045】 The first pulse tube 14 is a longitudinally-long metallic pipe-shaped member which has a hollow chamber into which refrigerant gas can flow, and refrigerant gas, which has a pressure waveform generated by the compression portion 4, flows into it. Here, an upper-end side of the first pulse tube 14 (another end) is adapted to a high-temperature end 14H, and a lower-end side of the first pulse tube 14 (an end) is adapted to a low-temperature end 14L. The low-temperature end 14L is placed on a lower side in order to inhibit the thermal convection of refrigerant gas.

【0046】 As shown in Fig. 1, an end of the first radiator 16 is connected with the high-temperature end 14H of the first pulse tube 14, and the first radiator 16 is placed on an outer side than a vacuum heat-insulation bath 24. Another end of the first radiator 16 is connected with an end 17a of a metallic first inertance tube 17 which is formed of a long pipe functioning as a first communication tube. The first inertance tube 17 has a function equivalent to reactance in electric circuit. The inside diameter of the first inertance tube 17 is smaller than the inside diameter of the first pulse tube 14 and the inside diameter of the first buffer tank 18. Another end 17b of the first inertance tube 17 is connected with the first buffer tank 18. The first buffer tank 18 has a tank chamber 18w whose volume is large.

【0047】 Here, the refrigerant gas in the first pulse tube 14 goes to and fro with respect to the inside of the first buffer tank 18

by way of the first inertance tube 17, and thereby the phase and pressure amplitude of the refrigerant gas is adjusted. Therefore, the first inertance tube 17 and the first buffer tank 18 can function as a pressure-waveform phase controlling element, which controls the pressure-waveform phase and pressure amplitude of refrigerant gas, for generating refrigeration at the low-temperature end 14L of the first pulse tube 14. The first inertance tube 17 and the first buffer tank 18 are placed on an outside of the vacuum heat-insulation bath 24, as shown in Fig. 1.

【0048】 As shown in Fig. 1, the low-temperature end 10L of the second cold accumulator 10 communicates with a second heat exchanger 30, which has a function of being capable of cooling refrigeration gas by means of heat exchange, by way of a pipe 19. The second heat exchanger 30 is disposed at the low-temperature end 20L of the second pulse tube 20 (a lower temperature than the low-temperature end 14L of the first pulse tube 14). The second pulse tube 20 is a long metallic pipe-shaped member which has a longitudinally-long hollow chamber into which refrigerant gas can flow. Here, the length of the second pulse tube 20 is set shorter than the length of the first pulse tube 14. Moreover, the inside diameter of the second pulse tube 20 is set smaller than the inside diameter of the first pulse tube 14. Therefore, the volume of the second pulse tube 20 is set smaller than the volume of the first pulse tube 14. An upper-end side of the second pulse tube 20 is adapted to a high-temperature end 20H, and a lower-end side of the second pulse tube 20 is adapted to a low-temperature end 20L. The low-temperature end 20L is disposed on a lower side in order to inhibit the thermal convection of refrigerant gas.

【0049】 At the high-temperature end 20H of the second pulse tube 20, a second radiator 21 having a cooling function is disposed. The second radiator 21 contacts thermally with the outer surface of the contact member 9's cylinder portion 9a by way of a flange portion 9b having heat transferability. As described above, on the inner surface of the contact member 9's cylinder portion 9a, a flow passage is disposed, in flow passage which the refrigerant gas cooled by refrigeration generated at the low-temperature end 14L of the first pulse tube 14 flows. Therefore, the second radiator 21 is cooled by the refrigerant gas flowing in the contact member 9's cylinder portion 9a.

【0050】 In other words, since the high-temperature end 20H of the second pulse tube 20 contacts thermally with the second radiator 21 and is cooled by the second radiator 21, as a result, the high-temperature end 20H of the second pulse tube 20 comes to be cooled by refrigeration generated at the low-temperature end 14L of the first pulse tube 14. Since the high-temperature end 20H of the second pulse tube 20 is thus maintained at a low temperature by the second radiator 21, even with an identical flow volume, it becomes advantageous for making the volume of the refrigerant gas in the second pulse tube 20 small, and it is possible to shorten the length of the second pulse tube 20. Therefore, it becomes advantageous for enhancing the compression ratio of a refrigeration circuit, and accordingly it is possible to make the refrigeration amount, which generates at the low-temperature end 20L of the second pulse tube 20, larger than the prior arts.

【0051】 In accordance with the present embodiment mode, a shield plate 25, which can function as a cooling element, is disposed, as

shown in Fig. 1. The shield plate 25 is made of a metal of good heat transferability, since a part 25m of the shield plate 25 contacts thermally with the low-temperature end 14L of the first pulse tube 14, as shown in Fig. 1, the shield plate 25 is cooled to a low temperature.

【0052】 With the shield plate 25 as a cooling element, a box-shaped shield case 26 contacts thermally. The shield case 26 is placed on a lower side of the shield plate 25, and forms a shield chamber 26w. The shield chamber 26w communicates with the vacuum heat-insulation chamber 24w, and is maintained in a high vacuum state in the same manner as the vacuum heat-insulation chamber 24w.

【0053】 As shown in Fig. 2, a metallic second inertance tube 22, which is formed of a long pipe, contacts thermally with the shield plate 25, and is held thereto. The second inertance tube 22 functions as a second communication pipe, which communicates the second buffer tank 23 with the second pulse tube 20, and has a function of throttling gas flow volume; and the inside diameter of the second inertance tube 22 is smaller than the inside diameter of the second pulse tube 20 and the inside diameter of the second buffer tank 23.

【0054】 Moreover, as shown in Fig. 1, a top portion 23u of the second buffer tank 23 contacts thermally with the shield plate 25, and is held thereto. The second buffer tank 23 is placed on the lower-surface side of the shield plate 25. The second buffer tank 23 has a tank chamber 23w whose volume is large. The volume of the tank chamber 23w is made smaller than the volume of the first buffer tank 18's tank chamber 18w. As set forth above, the second buffer tank 23 also contacts thermally with the shield plate 25 as a cooling

element. Thus, the second buffer tank 23 is cooled by the shield plate 25, and the refrigerant gas within the second buffer tank 23 is maintained at a low temperature.

【0055】 Here, the refrigerant gas in the second pulse tube 20 goes to and fro with respect to the inside of the second buffer tank 23 by way of the second inertance tube 22, and thereby the phase and pressure amplitude of the refrigerant gas, which is supplied to the second pulse tube 20, is adjusted. Therefore, the second inertance tube 22 and the second buffer tank 23 can function as a pressure-waveform phase controlling element, which controls the pressure-waveform phase of refrigerant gas, for generating refrigeration at the low-temperature end 20L of the second pulse tube 20.

【0056】 In accordance with the present embodiment mode, the second buffer tank 23 is not placed in air, but is disposed within the vacuum heat-insulation chamber 24w of the vacuum heat-insulation bath 24, as shown in Fig. 1. Especially, the second buffer tank 23 is disposed within the shield chamber 26w of the shield case 26 within the vacuum heat-insulation bath 24. The shield case 26 functions as a heat-radiation transmission inhibitor element for inhibiting the transmission of heat radiation from the outside.

【0057】 Accordingly, it is possible to maintain the refrigerant gas within the second buffer tank 23 at a much lower temperature. The inside of the vacuum heat-insulation chamber 24w of the vacuum heat-insulation bath 24 is connected with a vacuum pump 24x, and is maintained in a high-vacuum state (10^{-4} Torr or less ≒ 133 × 10^{-4} Pa or less). The vacuum heat-insulation bath 24 is good in terms of the heat insulatability.

【0058】 Note that wall bodies of the vacuum heat-insulation bath 24 are formed of a highly heat-insulative material which inhibits heat transmission. The shield case 26 is disposed within the vacuum heat-insulation bath 24, suppresses heat radiation from the outside, and is formed of a metal, which is of good heat transferability, as the substrate.

【0059】 In accordance with the present embodiment mode, the second cold accumulator 10, the second pulse tube 20 and the second radiator 21 are disposed within the shield chamber 26w of the shield case 26, in addition to the second buffer tank 23, as shown in Fig. 1, and their thermal contacts with the air are prohibited. As shown in Fig. 1, the first pulse tube 14 is outside the shield case 26, and is accommodated within the vacuum heat-insulation bath 24.

【0060】 In service, the pistons 2, 3 reciprocate with a frequency while facing to each other. Thus, the refrigerant gas within the compression portion 4 of the compressor 1 is compressed with the same frequency as that of the pistons 2, 3, and a pressure waveform for the refrigerant gas (helium in general) is generated. And, the gas-pressure resonance frequency within the first buffer tank 18 and first inertance tube 17, and the gas-pressure resonance frequency within the second buffer tank 23 and second inertance tube 22 are such that their dimensional specifications are set up so as to become a frequency which is virtually equal to that of the movements of the pistons 2, 3. Thus, at the low-temperature end 14L of the first pulse tube 14 as well as at the low-temperature end 20L of the second pulse tube 20, pressure waveforms, which are close to the Stirling cycle substantially, are obtained, and it is set up so that it is possible to obtain a refrigeration amount close

to the ideal at the low-temperature end 20L of the second pulse tube 20.

【0061】 For example, depending on the operational circumstances, 40-100 K refrigeration can be obtained at the low-temperature end 14L of the first pulse tube 14, and 10-30 K refrigeration can be obtained at the low-temperature end 20L of the second pulse tube 20. Depending on the operational circumstances, the vacuum heat-insulation bath 24 and shield case 26 have a function of inhibiting the heat transfer from the vacuum heat-insulation bath 24, and the temperature of the shield case 26's shield chamber 26W is 40-100 K approximately in general. The shield case 26 has a function of inhibiting the radiation heat from the vacuum heat-insulation chamber 24.

【0062】 In accordance with the present embodiment mode, the refrigerant gas, which has become a low temperature by refrigeration generated at the low-temperature end 14L of the first pulse tube 14, flows on the inner surface of the contact member 9's cylinder portion 9a. As a result, since the contact member 9 is cooled, the second radiator 21, which contacts thermally with the contact member 9, becomes a low temperature. Eventually, the high-temperature end 20H of the second pulse tube 20, which contacts thermally with the second radiator 21, is maintained at a low temperature so that it is maintained at a temperature which is virtually close to the temperature of the first pulse tube 14's low-temperature end 14L.

【0063】 Thus, in accordance with the present embodiment mode, since the high-temperature end 20H of the second pulse tube 20 can be maintained at a lower temperature by the second radiator 21, it becomes advantageous for reducing the gaseous volume of the

refrigerant gas within the second pulse tube 20, and the length of the second pulse tube 20 can be made shorter than the lengths of the second pulse tubes according to prior arts so that it is possible to downsize the second pulse tube 20.

【0064】 As described above, in accordance with the present embodiment mode, since the second buffer tank 23 is disposed within the vacuum heat-insulation chamber 24w of the vacuum heat-insulation bath 24, it is possible to suppress the thermal contact between the second buffer tank 23 and the air, and it is possible to always keep the second buffer tank 23 at a low temperature, and it is advantageous for enhancing the refrigeration capacity in the pulse tube refrigerator.

【0065】 Especially, since the second buffer tank 23 is disposed within the shield chamber 26w of the highly heat-insulatable shield case 26 which is placed within the vacuum heat-insulation bath 24, it is possible to keep the second buffer tank 23 at a much lower temperature, and eventually it is possible to keep the refrigerant gas within the second buffer tank 23 as well at a low temperature.

【0066】 Consequently, in accordance with the present embodiment mode, it becomes advantageous for further enhancing the compression ratio of the refrigerant gas within a cooling circuit, the refrigeration amount generated at the lower-temperature end 20L of the second pulse tube 20 enlarges, and it becomes advantageous for enhancing the refrigeration capacity of the pulse tube refrigerator.

【0067】 Further, in accordance with the present embodiment mode, the second inertance tube 22, which carries out flowing in and flowing out the refrigerant gas with respect to the second buffer tank 23, is disposed within the vacuum heat-insulation chamber 24w

of the vacuum heat-insulation bath 24, along with the second buffer tank 23. Accordingly, not only the thermal contact between the second buffer tank 23 and the air is suppressed, but also the thermal contact between the second inertance tube 22 and the air can be suppressed, and it is possible to always keep the second inertance tube 22 at a low temperature. Consequently, in accordance with the present embodiment mode, it becomes advantageous for further enhancing the compression ratio of the refrigerant gas within a cooling circuit, and the refrigeration amount generated at the lower-temperature end 20L of the second pulse tube 20 enlarges.

【0068】 Especially, as shown in Fig. 1, since the second inertance tube 22 is disposed within the shield chamber 26w of the shield case 26 within the vacuum heat-insulation bath 24, it is possible to keep the second inertance tube 22 at a much lower temperature, and it is possible to keep the refrigerant gas in the second inertance tube 22 at a low temperature. Consequently, in accordance with the present embodiment mode, it becomes advantageous for further enhancing the compression ratio of the refrigerant gas within a cooling circuit, and the refrigeration amount generated at the lower-temperature end 20L of the second pulse tube 20 enlarges.

【0069】 Furthermore, the shield plate 25 as the cooling element is cooled by the low-temperature end 14L of the first pulse tube 14, and the second inertance tube 22 contacts thermally with the shield plate 25. Accordingly, the second inertance tube 22 is cooled by refrigeration generated at the low-temperature end 14L of the first pulse tube 14 by way of the shield plate 25. Especially, since the inside diameter of the second inertance tube 22's flow passage is small, it is possible to cool not only the refrigerant gas flowing

on the outer peripheral side of the second inertance tube 22 but also the refrigerant gas flowing on the center-axis core side of the second inertance tube 22. Therefore, it is possible to efficiently cool the entirety of the refrigerant gas flowing in the second inertance tube 22.

【0070】 That is, in accordance with the present embodiment mode, since it is possible to efficiently cool the refrigerant gas in the second inertance tube 22 with the shield plate 25 as the cooling element, it is possible to keep the refrigerant gas flowing in the second inertance tube 22 at a much lower temperature. Hence, it becomes advantageous for further enhancing the compression ratio of the refrigerant gas within a cooling circuit, the high-temperature end 20H of the second pulse tube 20 becomes a much lower temperature, and the refrigeration amount generated at the lower-temperature end 20L of the second pulse tube 20 improves furthermore.

【0071】 Further, since it is possible to make the refrigerant gas flowing in the second inertance tube 22 a further low temperature, the flow-passage resistance of the second inertance tube 22 reduces so that it is possible to make the viscous loss of the gas flowing in the second inertance tube 22 less. As a result, since it is possible to make the phase of the refrigerant gas flowing into the high-temperature end 20H of the second pulse tube 20 and the gaseous amount favorable, the refrigeration capacity enlarges.

【0072】 When the refrigerant gas within the second inertance tube 22 can be cooled to a low-temperature side as described above, it is possible to clarify the peak of the resonance frequency of the gaseous pressures within the second buffer tank 23 and second

inertance tube 22, and it becomes advantageous for further improving the refrigeration amount generated at the low-temperature end 20H of the second pulse tube 20.

【0073】 Additionally, in accordance with the present embodiment mode, the second buffer tank 23 contacts thermally with the shield plate 25 as the cooling element, shield plate 25 which joins thermally with the low-temperature end 14L of the first pulse tube 14. Therefore, the second buffer tank 23 is cooled by refrigeration generated at the low-temperature end 14L of the first pulse tube 14 by way of the shield plate 25. Accordingly, it is possible to keep the refrigerant gas in the second buffer tank 23 at a much lower temperature. Hence, it becomes advantageous for further enhancing the compression ratio of the refrigerant gas within a cooling circuit, the high-temperature end 20H of the second pulse tube 20 becomes a much lower temperature, and eventually the refrigeration amount generated at the low-temperature end 20L of the second pulse tube 20 improves furthermore.

【0074】 As described above, in accordance with the present embodiment mode, since it is advantageous for enhancing the compression ratio of the refrigerant gas within a cooling circuit, it is possible to make the volume of the second pulse tube 20 less than the volumes of the second pulse tubes according to prior arts. Thus, it is possible to shorten the length of the second pulse tube 20. Accordingly, it is advantageous in view of inhibiting the vibrations of the second pulse tube 20, and is appropriate for using the pulse tube refrigerator in vibrating environments.

【0075】 Note that, in accordance the aforementioned embodiment mode, the second radiator 21, which is disposed at the high-temperature

end 20H of the second pulse tube 20, is brought into contact with the contact member 9 thermally, however, not limited to this, the second radiator 21 can be directly brought into contact with the low-temperature end 14L of first pulse tube 14.

【0076】 Moreover, the aforementioned embodiment mode is an example which is applied to a 2-stage pulse tube refrigerator, however, not limited to this, it can be applied to pulse tube refrigerators of 3 stages or more.

(Second Embodiment Mode)

【0077】 Fig. 3 illustrates a Second Embodiment Mode. The Second Embodiment Mode is a modified mode of the First Embodiment Mode. The Second Embodiment Mode is the same constitution as the First Embodiment Mode basically, and performs the same operations and effects basically. Common parts are designated at common symbols. Hereinafter, portions, which differ from the First Embodiment Mode, will be described mainly. Specifically, a sub cold accumulator 40 is disposed between the first heat exchanger 15 and pipe 13 of the First Embodiment Mode. And, the shield plate 25 as the cooling element is brought into contact with and disposed at the high-temperature end of the sub cold accumulator 40. In accordance with the Second Embodiment Mode, the temperature of refrigeration generated at the low-temperature end 14L of the first pulse tube 14 is low sufficiently, and it is a modal example in the case that the temperature at the high-temperature end 20H of the second pulse tube 20 can be higher than the temperature at the low-temperature end 14L of the first pulse tube 14.

(Third Embodiment Mode)

【0078】 Fig. 4 illustrates a Third Embodiment Mode. The Third

Embodiment Mode is a modified mode of the First Embodiment Mode. The Third Embodiment Mode is the same constitution as the First Embodiment Mode basically, and performs the same operations and effects basically. Common parts are designated at common symbols. Hereinafter, portions, which differ from the First Embodiment Mode, will be described mainly. Specifically, as shown in Fig. 4, the second buffer tank 23 contacts thermally with the shield plate 25 as the cooling element, and is cooled by refrigeration generated at the low-temperature end 14L of the first pulse tube 14 by way of the shield plate 25. Accordingly, it is possible to keep the refrigerant gas in the second buffer tank 23 at a much lower temperature. As shown in Fig. 4, the shield plate 25 has a flanged portion 25r, which is bent toward the second buffer tank 23 and contacts thermally with an outer wall surface of the second buffer tank 23, for facilitating the transfer of heat. The heat-transfer facilitating flanged portion 25r increases the contact portion (heat-transfer area) with the second buffer tank 23 to enhance the cooling ability of the refrigerant within the second buffer tank 23.

(Fourth Embodiment Mode)

【0079】 Fig. 5 illustrates a Fourth Embodiment Mode. The Fourth Embodiment Mode is a modified mode of the First Embodiment Mode. The Fourth Embodiment Mode is the same constitution as the First Embodiment Mode basically, and performs the same operations and effects basically. Common parts are designated at common symbols. Hereinafter, portions, which differ from the First Embodiment Mode, will be described mainly. Specifically, the most part of the second buffer tank 23 is placed within the vacuum heat-insulation chamber

24w of the vacuum heat-insulation bath 24, however, only a part (upper-end portion) of the second buffer tank 23 is exposed beyond the vacuum heat-insulation bath 24, as shown in Fig. 5. However, among the second buffer tank 23, in the part being exposed beyond the second buffer tank 23, a heat-insulation material 23m of good heat insulatability is placed. The heat-insulation material 23m can inhibit the temperature increment of the refrigerant gas within the second buffer tank 23.

(Fifth Embodiment Mode)

【0080】 Fig. 6 illustrates a Fifth Embodiment Mode. The Fifth Embodiment Mode is a modified mode of the First Embodiment Mode. The Fifth Embodiment Mode is the same constitution as the First Embodiment Mode basically, and performs the same operations and effects basically. Hereinafter, portions, which differ from the First Embodiment Mode, will be described mainly. Common parts are designated at common symbols. Specifically, the second buffer tank 23 is placed within the vacuum heat-insulation chamber 24w of the vacuum heat-insulation bath 24, however, only a tube-shaped portion 23x, which protrudes from the second buffer tank 23, is exposed beyond the vacuum heat-insulation bath 24. To the tube-shaped portion 23x, a measuring gauge 23k, such as sensors for detecting physical quantities like the pressure and temperature of the refrigerant gas within the second buffer tank 23, is installed, depending on needs. Since the measuring gauge 23k is exposed beyond the vacuum heat-insulation bath 24, it is advantageous for the maintenance and inspection of the measuring gauge 23k.

(Sixth Embodiment Mode)

【0081】 Fig. 7 illustrates a Sixth Embodiment Mode. The Sixth

Embodiment Mode is a modified mode of the First Embodiment Mode. The Sixth Embodiment Mode is the same constitution as the First Embodiment Mode basically, and performs the same operations and effects basically. Hereinafter, portions, which differ from the First Embodiment Mode, will be described mainly. Specifically, since the length of the second inertance tube 22 is long, the entirety or a part of the second inertance tube 22 is wound around the low-temperature end 14L of the first pulse tube 14 in the peripheral direction in order to use the second inertance tube 22 effectively. The second inertance tube 22 is cooled by refrigeration generated at the low-temperature end 14L (cooling element) of the first pulse tube 14. The second inertance tube 22 is placed within the vacuum heat-insulation chamber 24w.

【0082】 (Others) The following technical ideas can be grasped from the aforementioned descriptions.

【0083】 Additional Note No. 1: a pulse tube refrigerator being characterized in that, in claim 1, the buffer tank communicates with the high-temperature end of the pulse tube by way of an inertance tube having a flow passage whose inside diameter is smaller than an inside diameter of the pulse tube.

【0084】 Additional Note No. 2: a pulse tube refrigerator being characterized in that, in additional note No. 1, the inertance tube is placed within the vacuum heat-insulation chamber of the vacuum heat-insulation bath.

【0085】 Additional Note No. 3: a pulse tube refrigerator being characterized in that, in additional note No. 1 or 2, the pulse tube is constituted of a first pulse tube, into which refrigerant gas with a pressure waveform flows, one of whose ends is adapted to a

low-temperature end, the other one of whose ends is adapted to a high-temperature end, and a second pulse tube, one of whose ends is adapted to a low-temperature end, the low-temperature end becoming a lower temperature than the low-temperature end of the first pulse tube, the other one of whose ends is adapted to a high-temperature end.

【0086】 Additional Note No. 4: a pulse tube refrigerator being characterized in that, in additional note No. 3, the cold accumulator is disposed between the pressure-waveform generating device, the first pulse tube and the second pulse tube, and pre-cools the refrigerant gas to be flowed into the first pulse tube and/or the second pulse tube.

【0087】 Additional Note No. 5: a pulse tube refrigerator being characterized in that, in additional note No. 3, the pressure-waveform phase controlling element has a first inertance tube communicating with the high-temperature end of the first pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the first pulse tube, a first buffer tank communicating with the high-temperature end of the first pulse tube by way of the first inertance tube, a second inertance tube communicating with the high-temperature end of the second pulse tube and having a flow passage with a smaller inside diameter than an inside diameter of the second pulse tube, and a second buffer tank communicating with the high-temperature end of the second pulse tube by way of the second inertance tube.

【0088】 Additional Note No. 6: a pulse tube refrigerator being characterized in that, in additional note No. 5, a cooling element contacting thermally with the low-temperature end of the first pulse

tube and being cooled by refrigeration from the low-temperature end of the first pulse tube is disposed, and the cooling element is brought into contact with the second inertance tube thermally.

【0089】 Additional Note No. 7: a pulse tube refrigerator being characterized in that, in additional note No. 5 or 6, a cooling element contacting thermally with the low-temperature end of the first pulse tube and being cooled by refrigeration from the low-temperature end of the first pulse tube is disposed, and the cooling element is brought into contact with the second buffer tank thermally.

【0090】 Additional Note No. 8: a pulse tube refrigerator being characterized in that, in additional note Nos. 5 through 7, at least a part of the second inertance tube is brought into contact with the low-temperature end of the first pulse tube thermally.

INDUSTRIAL APPLICABILITY

【0091】 The present invention can be utilized for pulse tube refrigerators.